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ARTEMIS

Surface Systems Capability Gaps for Enabling NASA’s Sustainable Lunar Operations

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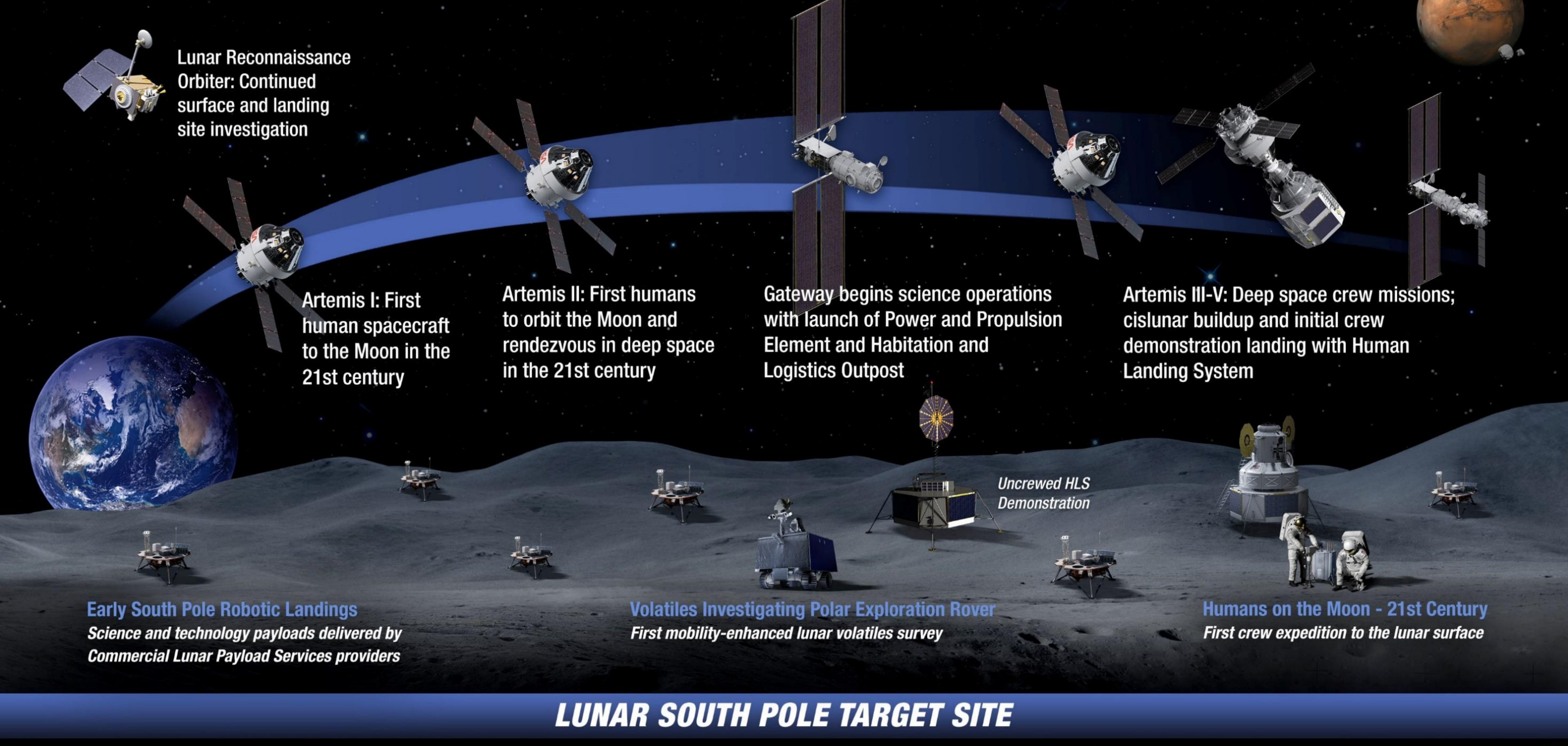
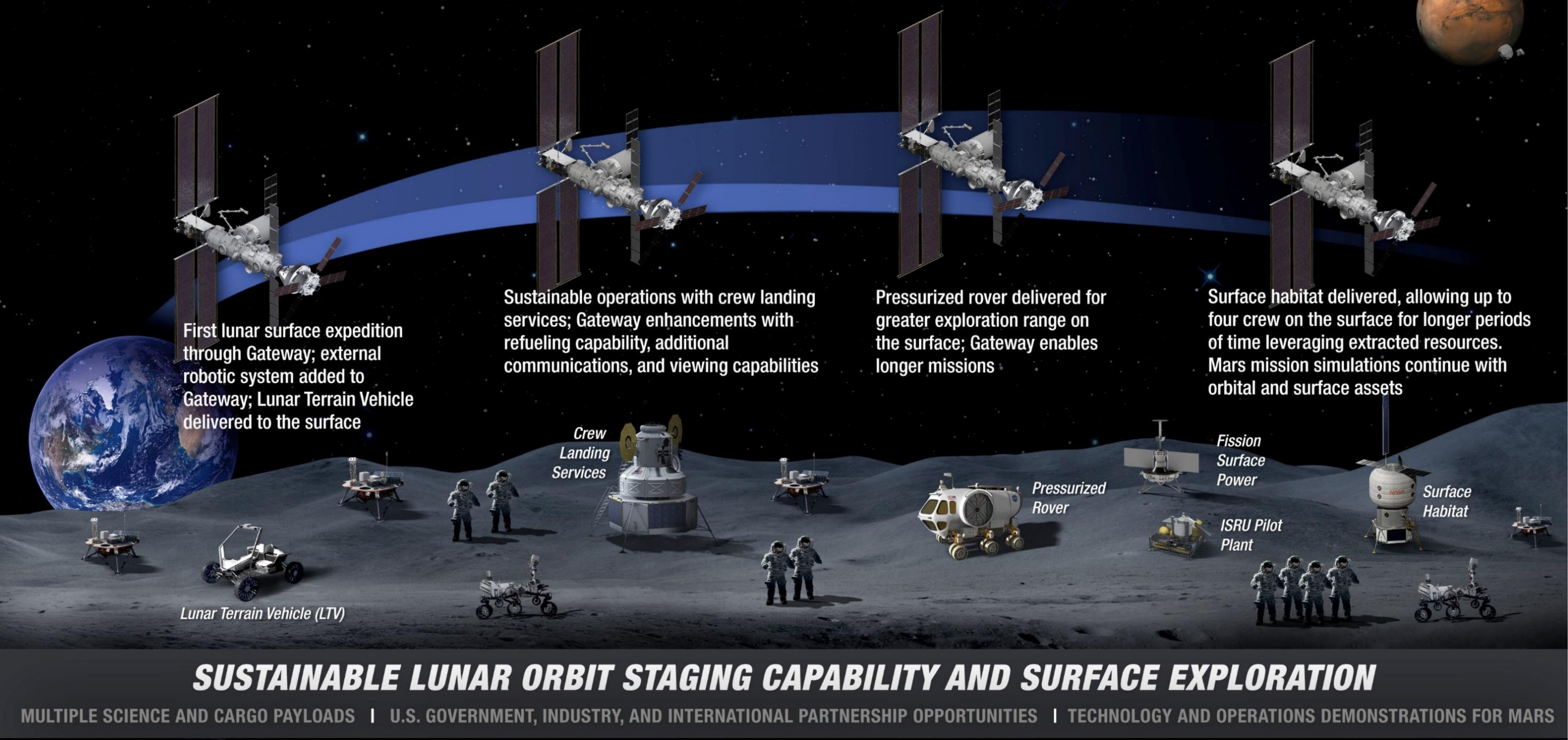
Artemis: Landing Humans On the Moon



(Image: NASA)

Artemis Base Camp Buildup



(Image: NASA)

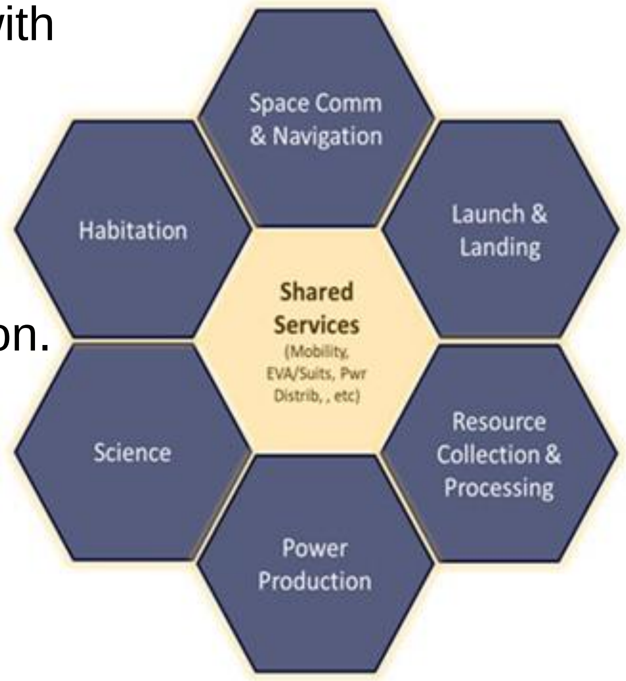
2020 NASA Technology Taxonomy

- NASA uses a Technology Taxonomy to manage and communicate the extensive and diverse technology portfolio activities to enable NASA missions.
- TX-13 Ground, Test, and *Surface Systems* Taxonomy
  - ➢ Captures technological innovations in capabilities, infrastructure, and processes to prepare, assemble, validate, execute, support, and maintain aeronautics and space activities and operations, on Earth and on other planetary surfaces.
- The *Surface Systems* portion of the TX-13 Taxonomy, specifically Uncrewed Surface Operations, is the focus of the Capability Gaps identified in this presentation for enabling NASA's Sustainable Lunar Surface Operations.

2020 NASA Technology Taxonomy *(Image: NASA)*
https://www.nasa.gov/sites/default/files/atoms/files/2020_nasa_technology_taxonomy.pdf

Uncrewed Surface Operations

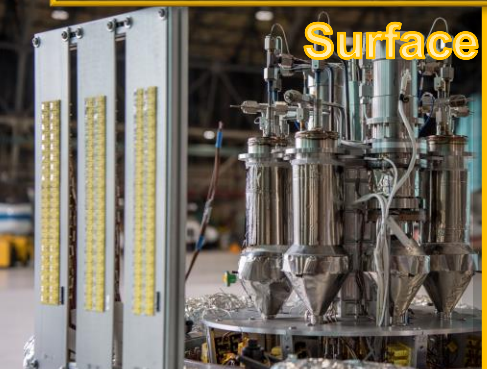
- Operations that occur on the surface, when crew may or may not be present, but which are designed to operate independently of surface crewed activities.
- Elements, interfaces, technical aspects, and operations and maintenance involved with a surface architecture for Sustained Lunar Exploration and Development.
    - ➢ Launch and Landing site planning criteria, preparations, and construction.
    - ➢ Management of crew support elements when the crew is not available.
    - ➢ Surface utility infrastructure: surface-based power, communications & navigation.
    - ➢ Resource Collection and Processing - In-situ resource utilization (ISRU) pilot plant and propellant handling.
    - ➢ Commodity management and storage systems.
    - ➢ Logistics management systems.

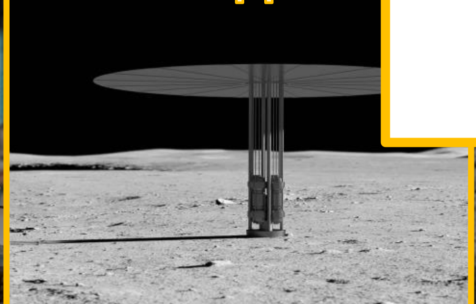


- Emplacing and building infrastructure, systems and robotic missions to enable sustained lunar surface operations.
- Enables greater use of crew time during crewed surface missions to focus on science and exploration.

Lunar South Pole
Site Operations & Support Functions

Surface Power Support


Kilopower Nuclear Reactor
(Image: NASA)


Fission Surface Power
(Image: NASA)

Lunar Surface Innovation Consortium (LSIC)
(Image: NASA/Johns Hopkins Applied Physics Lab/Ben Smith)

Capabilities Integration

CAPABILITY | The ability to complete a task or meet an exploration objective through Architecture, Engineering, Development, Technology, Operations or Research for a given set of constraints and level of risk.

Current Capabilities

Capabilities we have today, established and flight validated on the International Space Station, robotic missions….

THE DIFFERENCE IS THE

GAP

Future Needed Capabilities

Anticipated future capabilities based on national space policy, planned mission architectures, agency strategic planning, and standards.

GAP CLOSURE APPROACH

- Technology
- Development
- Engineering
- Scientific Research
- Architecture Changes
- Operational Concepts
- Policy Decisions

TEST LOCATION

- Mars surface
- Mars spacecraft
- Lunar surface
- Gateway/Cislunar
- Orion spacecraft
- ISS/LEO
- Ground Activity

MILESTONE CLOSURE

- Tech Demo
- Research Utilization
- Analog Activities
- Verification & Validation
- Qualification Test

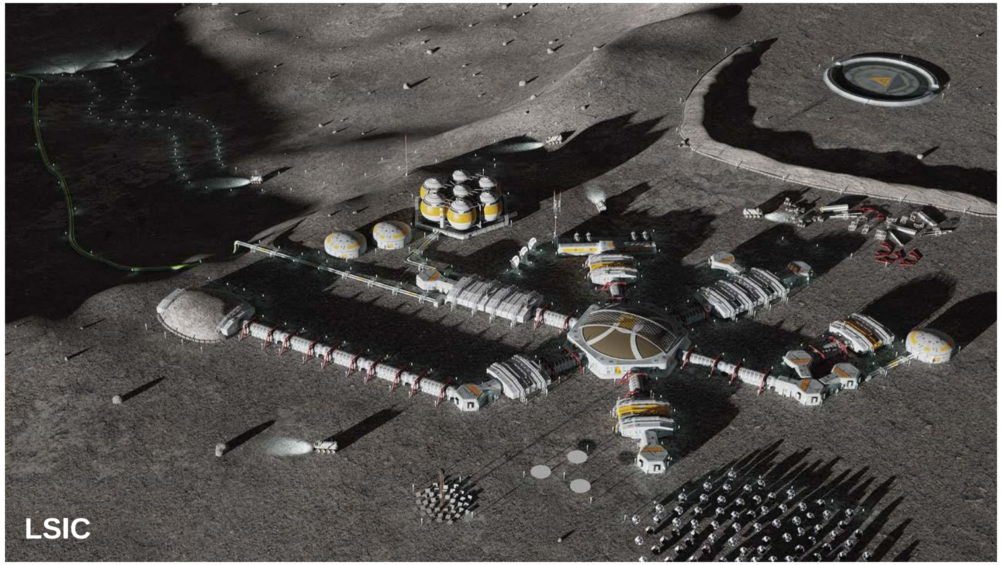
OUTCOMES

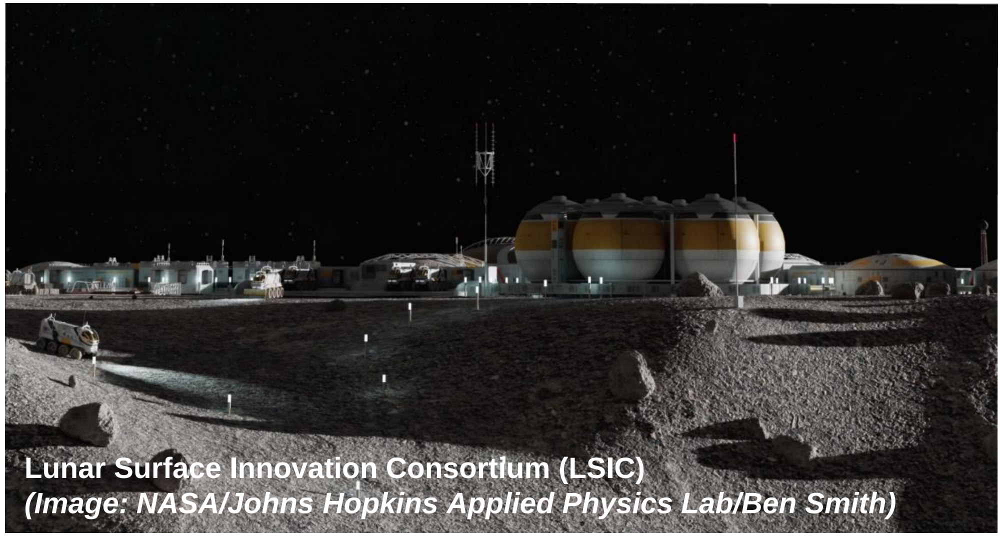
- TRL Advancement
- Technology Infusion
- Updated Procedures
- Countermeasures
- Updated Standards
- Updated Mission Profile

TX-13 Architecture Capability Gaps

Uncrewed Surface Systems Architecture Gaps

- **Standardized Architectures and Interfaces (commonality, interoperability, and interchangeability)**
  - ➢ Reduce maintenance/repair requirements, improve maintainability of systems, and increase robotic/ autonomous surface operations to enable greater use of crew time to focus on science and exploration.
- **Multi-Element Systems Engineering and Integration**
  - ➢ Integrate distributed analog test beds (physical or simulated) into the surface architecture approach and provide high-fidelity, mission-focused, process simulations and visualizations for surface operations to assess the functional flows and operational scenarios.
- **Design for Supportability**
  - ➢ Maintainability, repairability, commonality in spares, simplified architectures for commodities, and infrastructure for Food Production capability.

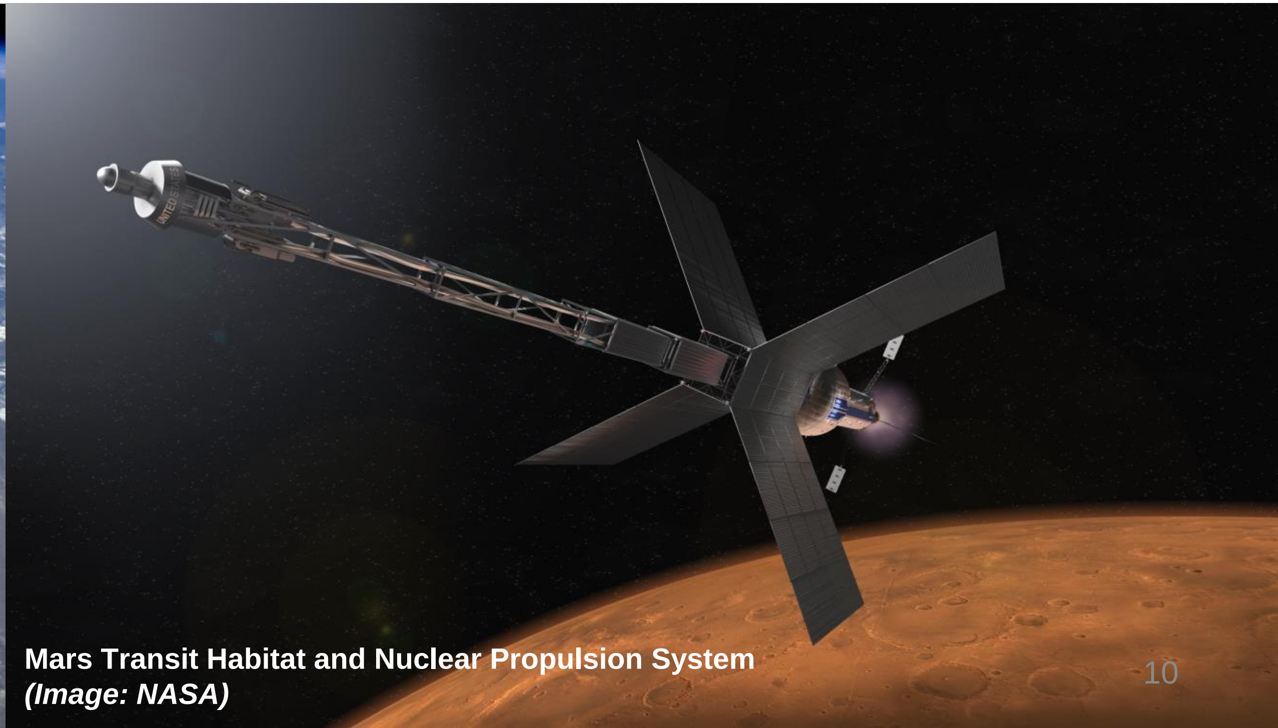

LSIC


Lunar Surface Innovation Consortium (LSIC)
(Image: NASA/Johns Hopkins Applied Physics Lab/Ben Smith)

Ground Systems Architecture Gap

- **Nuclear Payload Processing and Launch Approach**
  - Integration of Nuclear Propulsion payloads (nuclear thermal or MegaWatt Class electric) with the launch vehicle for the Mars Transportation system.
  - Certification for ground processing of nuclear payloads/spacecraft at the launch site (facilities, equipment, methodologies for handling, servicing, testing, and storage), including launch approval processes for Fission Power and Propulsion Systems.

Nuclear Thermal Rocket Propelled Mars Transfer Vehicle in LEO
(Image: NASA)

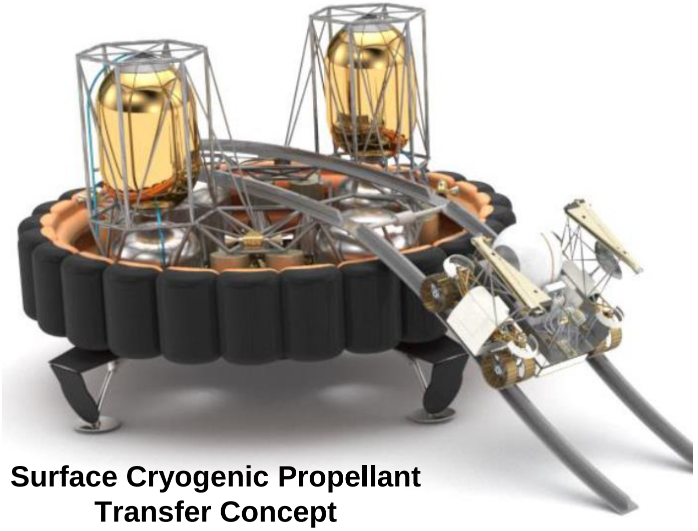


Mars Transit Habitat and Nuclear Propulsion System
(Image: NASA)

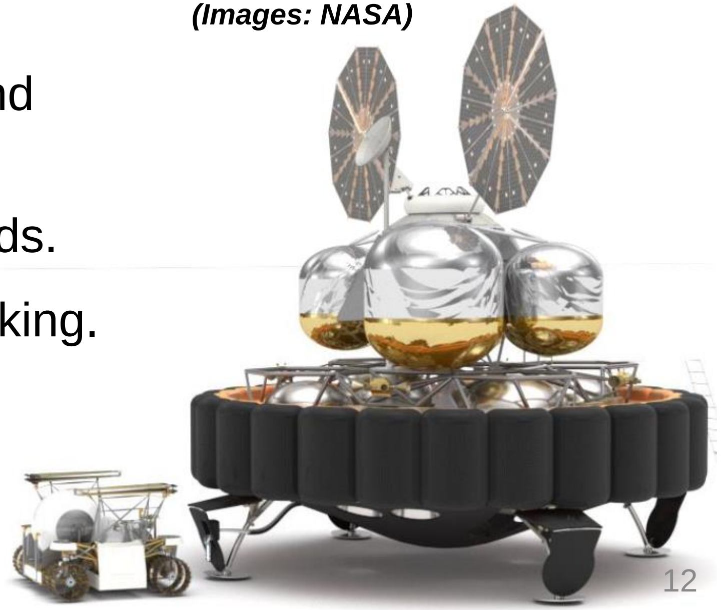
TX-13 Technology Capability Gaps

Uncrewed Surface Systems Technology Gaps

- **Automated/Autonomous Cryogenic Loading, Transfer, Servicing, and Storage of Commodities**
  - ➢ High-fidelity physics-based cryogenic-thermal models and simulations capable of real-time and faster than real-time performance.
  - ➢ High-fidelity models and simulations for complex systems and automated/autonomous algorithms for uncrewed surface applications.
- **Health Determination and Fault Management**
  - ➢ Prediction, prognosis and anomaly detection capabilities.
  - ➢ Detection, isolation, and recovery of systems and components faults and degradation.
  - ➢ Test and Evaluation (T&E) and Verification and Validation (V&V) methods.
  - ➢ Robust V&V capabilities for achieving trusted autonomy in decision-making.
  - ➢ Human interfaces for proximal and remote operators in the surface domain for varying levels of control and intervention.



Surface Cryogenic Propellant Transfer Concept
(Images: NASA)



Uncrewed Surface Systems Technology Gaps

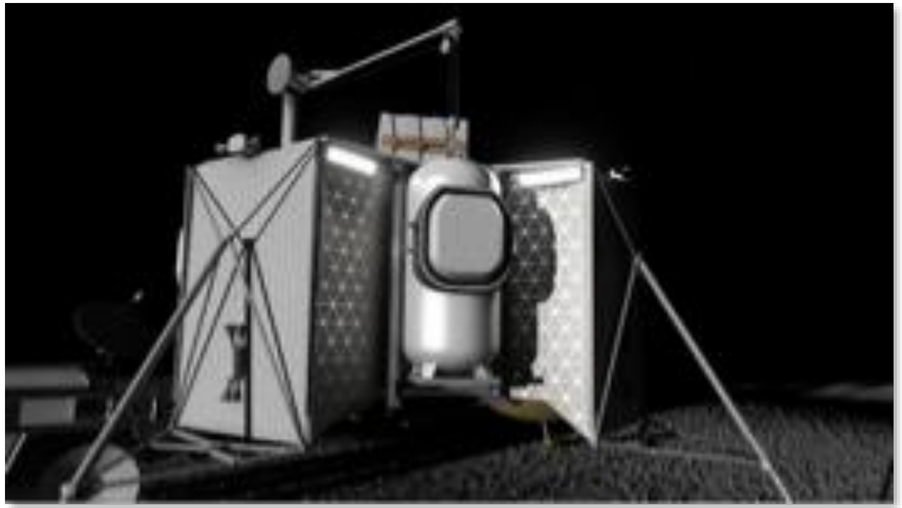
- **Automated/Autonomous Planning and Scheduling**
  - ➢ Asset management tools and applications (e.g. sensing, perception, reasoning, and actuation).
  - ➢ Scheduling and prioritization capabilities, human-machine information interactions, sensor/data fusion.
  - ➢ Automated/autonomous decision making for uncrewed surface operations.

Notional 2030 Uncrewed Lunar Surface Timeline
(Image: NASA)

- **Automated/Autonomous Inspection, Maintenance Repair (IMR)**
  - ➢ Robotic caretakers for maintenance needs.
  - ➢ Self-diagnosis in systems and components (e.g., Condition Based Maintenance).
  - ➢ Robotic Line Replacement Unit (LRU) repair and replacement.
  - ➢ Hazards assessment and resolution.
  - ➢ Multi-agent collaboration and interaction of the surface caretakers for performing IMR.
  - ➢ Interoperable capabilities to reduce/optimize logistics requirements.
  - ➢ Robust V&V capabilities for achieving trusted autonomy in IMR methods, techniques, processes.
  - ➢ Maintenance and repair common toolkits and test equipment.

Uncrewed Surface Systems Technology Gaps

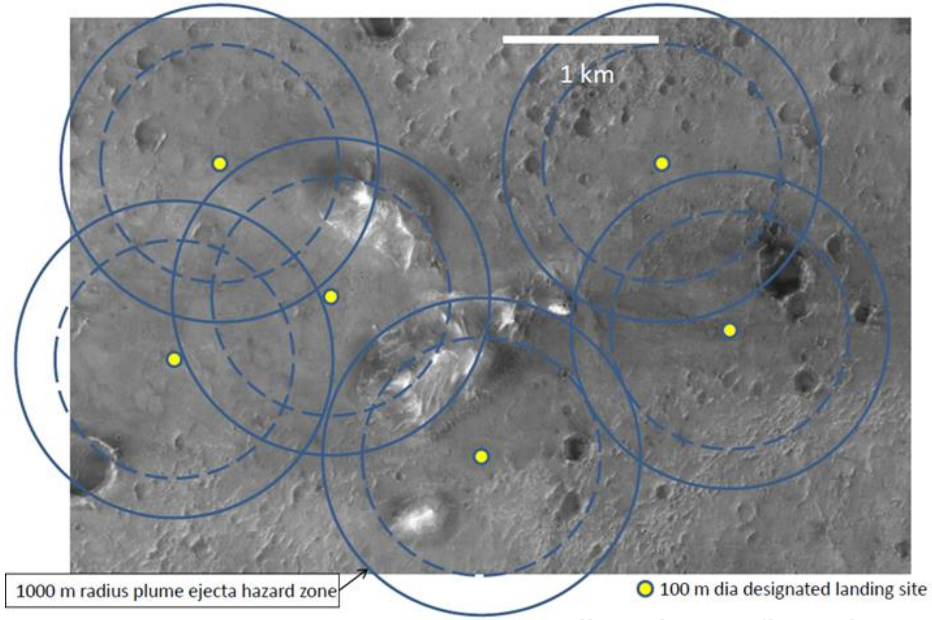
- **Logistics Management and Reliability**
  - ➢ Optimization/reduction of logistics needs (design for supportability, commonality, maintainability, reusability).
  - ➢ Commonality of maintenance equipment, tools, consumables.
  - ➢ Automated/autonomous asset tracking and personnel location.
  - ➢ Inventory management.
  - ➢ Maintenance and repair common toolkits and test equipment.
  - ➢ Intelligent Devices (sensors, actuators, electronics with self-diagnosis capabilities, calibration on demand, self-healing capabilities, etc.).
  - ➢ Waste management (repurposing, recycling, and disposal of materials).
  - ➢ Reduce crew involvement for maintenance and recovery.
  - ➢ Counterfeit part countermeasures, supply chain and supplier economic resilience modeling, digital product lifecycle management, service life prediction methods, built-in test enhanced life forecasting, calibration methods for surfaces systems, and additive manufacturing of spare parts using in-situ surface materials.



Notional Uncrewed Logistics Handling
(Image: NASA)

Uncrewed Surface Systems Technology Gaps

- **Launch and Landing Site Preparation**
  - ➢ Selecting, surveying, characterizing, and leveling.
  - ➢ Communication and navigation beacons near the site.
  - ➢ Assess launch induced environment effects (liftoff foreign object debris/ damage, ejecta on vehicle/lander, site infrastructure & nearby assets).
  - ➢ Assess natural environments to critical assets (e.g., radiation).
  - ➢ Blast protection of equipment emplaced on the surface.
  - ➢ Site maintenance: inspecting the area, removing debris, assessing damage, and refurbishing the launch site.
  - ➢ Surface Equipment and tools for preparing surface and moving regolith (specialized work packages).
  - ➢ Model and assess the integrated launch and landing site for total effects.

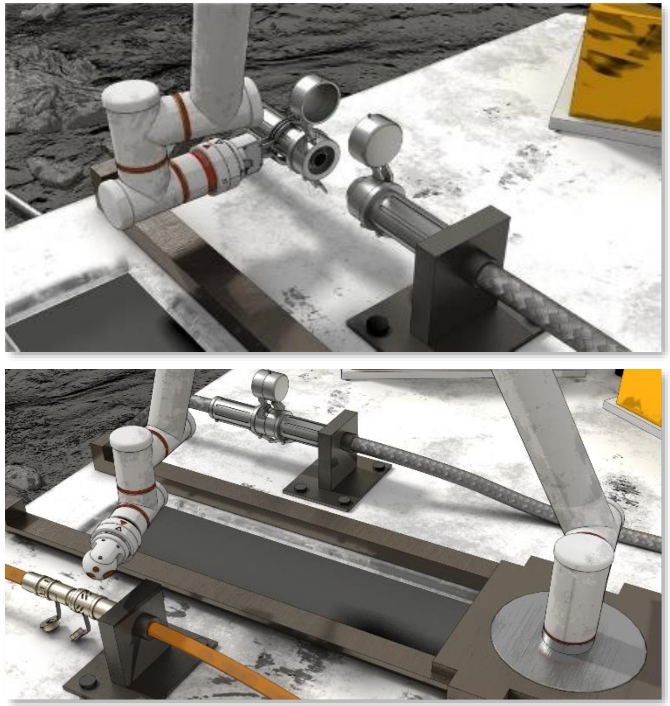


Landing Site Configurations
(Image: NASA)

Lunar Surface Innovation Consortium (LSIC)
(Image: NASA/Johns Hopkins APL/Ben Smith)

Uncrewed Surface Systems Technology Gaps

- **Commodity Management**
  - Storing, monitoring, purging, sampling, and transferring commodities for use by ascent vehicles and surface infrastructure elements.
  - Autonomous recovery of commodity losses, autonomous detection and isolation of leaks, lightweight, high reliability components, and autonomous, real-time, in-situ sampling/analysis and transfer.
- **Automated Umbilicals and Dust Tolerant Interfaces**
  - Uncrewed fluid, gas, electrical and physical/wireless data transfer between architectural elements.
  - Long-life soft seals for repeated use.
  - Protection of interfaces and actuation mechanisms from extreme surface environments (dust, temperature variations, high winds, etc.).
  - Lightweight, low separation force, high-reliability, dust-tolerant, leak-tight, self-aligning, long-life connectors and umbilicals.
  - Automatic connection to surface elements, as well as autonomous, dust tolerant and dust mitigating umbilical and data mating.



Dust-tolerant Fluid Mating and Inspection ***(Images: NASA)***

Automated Umbilicals ***(Image: NASA)***

TX-13 Engineering Capability Gaps

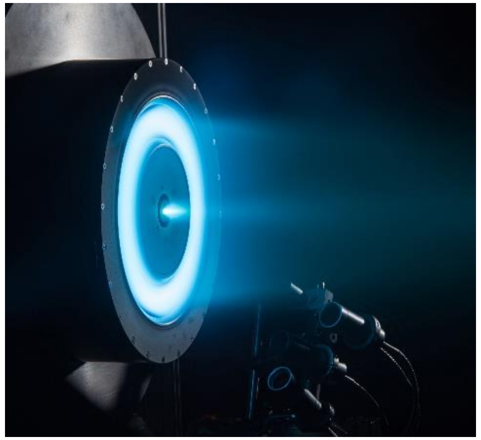
Ground and Surface Systems Engineering Gaps

- **High-Purity Propellant Production for Ground and Surface Applications**
  - ➢ Industrial scale production and availability of high purity Methane for propellant use; multi-tanker loads are required.

- **Large-Scale Xenon Servicing Capabilities**
  - ➢ Launch site infrastructure (including facilities, equipment, methodologies, and an experienced support team) for storage, handling, sampling, and transfer of large quantities (50 to 250 tons) of propellant grade xenon to support Nuclear Electric Propulsion Mars mission concepts.

Composition of Atmospheric Air (Volume %)

N_2	78.06
O_2	20.95
Ar	0.93
CO_2	0.033
Ne	0.0018
He	0.000524
CH_4	0.0002
Kr	0.00011
H_2	0.00005
N_2O	0.00005
Xe	**0.0000087**
O_3	0.000007
H_2O	1.57 (@ 50% RH & 25°C)



Xenon for High-Power Electric Propulsion:
12.5-kW Hall Effect Rocket with Magnetic Shielding (HERMeS)
Technology Demonstration Unit (TDU)-1 ***(Image: NASA)***

MIL-PRF-32207A

PERFORMANCE SPECIFICATION

PROPELLANT, METHANE

This specification is approved for use by all Departments and Agencies of the Department of Defense.

Grades

- A – 98.7% purity
- B – 99.9% purity
- C – 99.97% purity

(Image: Military and Government Specs & Standards)

Conclusions

Capability Gaps for Sustainable Lunar Operations

- **Integrated Exploration Capabilities Gap List**
  - ➢ An iterative development process that aims for successive improvements through refinements of the annual data call, updates to the capability gap data and closure pathways that are needed, and incorporation of more detailed architectural information developed through Exploration Mission strategic analysis cycles.
  - ➢ It serves as the basis of opinion for Exploration Systems technology development and mission needs and informs NASA's investment portfolios and architecture studies.
- **Uncrewed Lunar Surface Operations**
  - ➢ Lunar surface time in absence of crew accounts for greater than 95% of short stay surface missions.
  - ➢ Uncrewed Surface Operations mission segment includes robotic science/logistics delivery, surface propellant transfers (especially those involving point-to-point transport between Mars/Analog landing zones), surface maintenance operations, necessary assembly and inspection, and remote science operations.
  - ➢ The closure of the Uncrewed Surface Systems Capability Gaps identified will enable NASA's Sustainable Lunar Surface Operations.

QUESTIONS?

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